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The gritty problem of Moon dust

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NEIL ARMSTRONG nearly slipped on it. It irritated the Apollo astronauts' eyes and wore through their spacesuits. It even caused their moon buggies to overheat. Moon dust is seriously nasty stuff. "It gets all over everything," says Paul Carpenter, an engineer at BAE Systems in Huntsville, Alabama, a contractor for NASA. "During Apollo, it caused degradation of optical equipment, it got into the lunar module and made it back into the command module."

Last year President Bush announced plans to send humans to the moon and Mars. As the purse strings loosen and the money begins to flow, engineers are beginning to realise that moon dust is one problem they can no longer sweep under the carpet. "Dust is the number one concern in returning to the moon," says Apollo astronaut John Young.

Its effect on the astronauts' space suits was especially severe. The microscopic abrasive particles wore through the fabric, coated life-support systems and clogged up joints so much that the astronauts could hardly bend their elbows or seal their gloves. After only three moon walks the suits were essentially ruined. There is no way they could have been brought out a fourth time, says Larry Taylor of the University of Tennessee in Knoxville. But as they look for solutions, researchers are recognising that the lunar soil is not only a menace - it is also a potential resource.

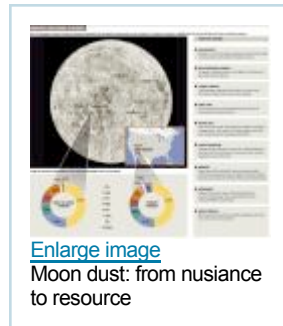
To the naked eye, lunar soil looks rather ordinary, just a dark grey powder. You might think you could scoop up something like it on a black-sand beach in Hawaii. But moon dust is quite literally out of this world. A microscopic view reveals a mixture of basalt fragments, beautiful round beads of volcanic glass, sharp fragments of broken glass and complicated particles called agglutinates, which consist of pieces of rock or mineral welded together by glass. The variety of particles is a testament to the moon's 4 billion years of pummelling by meteorites.

Large meteorites made the giant craters that scar the lunar landscape. But it is the smallest ones, the micrometeorites, that produced the moon's ravaged soil, or regolith. They break up pebbles and sand into finer particles and glue them together. "These things are going at 160,000 kilometres per hour when they hit the surface," says Taylor. "Every time these particles hit the soil, they melt a little bit of it to a temperature of 1000 to 2000 °C. That sticks things together into agglutinates." Luckily there is nothing like this on Earth: micrometeorites simply burn up in our thick atmosphere.

It is the weirdness of lunar soil that raises hopes of hitting pay dirt on the moon. One of NASA's favourite slogans at the moment is "in situ resource utilisation", or what people in an earlier age called living off the land. Researchers are devising ways to extract hydrogen and oxygen from lunar soil, providing the astronauts with air to breathe and, potentially, with the moon's first valuable export - rocket fuel for missions to Mars or for satellites in Earth orbit. Near the lunar poles the soil may contain ice deposits that can be melted for water. The soil itself could be melted with microwaves, making it possible to build roads and igloos out of jet-black lunar glass. And eventually the iron-rich moon dust might be mined and transformed into steel.

Carpenter and Taylor are among those who are starting to prepare for this future. But they need one commodity that is in desperately short supply: "simulant", NASA-speak for imitation lunar soil. In January Carpenter, with Laurent Sibille of BAE Systems, organised a workshop in Huntsville to decide what is required to make a sufficiently convincing fake.

Why use an imitation instead of the real stuff? The answer is that there is not enough of it. The Apollo

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Moon dust: from nuisance to resource

astronauts brought about 380 kilograms of rocks and soil back from the moon, and those samples are guarded at the Johnson Space Center in Houston, Texas, like a national treasure. By comparison Taylor reckons the demand for lunar simulant is around 1000 tonnes - and even that may be an underestimate. "I personally know of one company that expects to use 600 tonnes," he says. Some experiments, such as toxicity tests, may require only a few kilograms of simulant. But large-scale experiments, including habitat and road building, will require a great deal more.

That's why, in the early 1990s, NASA developed a simulant called JSC-1, which contained particles of a similar size and chemical make-up to lunar regolith (see Diagram). "JSC-1 was made from volcanic ash from a quarry near Flagstaff, Arizona," says David McKay of the Johnson Space Center, who worked with James Carter of the University of Texas at Dallas to produce it. The ash, which is ordinarily used to grit roads, is coarser than moon dust, so they took it to a local mill where it was ground to a flour-like consistency. Then Carter combined the pulverised ash with some of the original to get the right mix of flour, sand and pebbles.

Faking it

By all accounts, JSC-1 was a success. It was close enough to real moon soil in consistency and chemistry for several proof-of-concept experiments. "We extracted oxygen from it, using hydrogen reduction. And we made bricks with the compressive strength of concrete by heating the simulant to 900 °C or so," says McKay. JSC-1 was also used to test materials for the next generation of space suits.

Unfortunately the surrogate moon dust proved to be a bit too popular. Johnson Space Center never charged anyone a dime for it, though McKay says it cost more than \$1000 a tonne to make. Over the years, the original stock of 25 tonnes has dwindled to nothing, and thanks to President Bush's decision last year, there is suddenly an urgent need for more.

At the Huntsville workshop, researchers agreed that at least two and perhaps three "root" simulants would be needed this time. One, a clone of JSC-1, would mimic the basaltic composition of the moon's maria - flat plains once thought to be seas - while the second would replicate the more aluminium-rich regolith of the highland regions. A third might be developed to represent the soil in the permanently shaded regions near the moon's poles, which may contain small amounts of water ice. "If we had these root simulants and worked only with them, at least everyone would have a common starting point," says Taylor. He emphasises that "one simulant does not fit all". Researchers would have to make modifications to study some of the more exotic properties of moon dust - and there are plenty of those.

Explosive ice

Consider the icy polar regolith, for example. According to Jeff Taylor of the University of Hawaii in Honolulu, the temperatures in the crater bottoms, which never receive sunlight, are so low that any water in them would not adopt the usual crystalline form you find in your freezer. Instead it would have an irregular structure. Like the comets it came from, this amorphous ice may contain trapped gases such as carbon dioxide that vent explosively when heated. Clearly it would be better to find out about this on Earth than on the moon.

Or consider one of Larry Taylor's favourite ideas: microwaveable moon dust. Taylor still has a stash of real regolith left over from his days as a project scientist for Apollo. It is full of ultra-fine grains of elemental iron instead of the iron oxides found on Earth. Pure iron is never found in Earth's soil because water would very quickly cause it to rust.

Elemental iron absorbs microwaves at the frequency used by domestic microwave ovens, and it gets hot, really hot. "It will start to melt at 1200 °C before your coffee even boils," says Taylor. On the moon that's high enough to melt the glassy particles around it too. If enough of them melt they will form a smooth sheet of glass.

Taylor says this idea could prevent the astronauts kicking up so much dust. In advance of a manned landing, he would send a robotic rover equipped with microwave generators. "I'd put magnetrons on the back of a wagon, sinter the soil and make myself a paved landing pad and roads," he says. The microwave generators could be used for other purposes after the astronauts land. "Suppose my shovel broke. I could pass my microwave wand over it, melt the moon dust and couple it back together. I could melt the soil to any shape I want. I could make bricks and build a sandcastle." Or perhaps a lunar igloo.

Taylor is working on ways to make fine-grained iron particles to add to the root simulant, so he can test his ideas.

Other researchers may want to customise their lunar simulant in different ways. Russ Kerschmann is chief of the life sciences division at NASA's Ames Research Center in Moffett Field, California, and the only biologist at the Huntsville workshop. He hopes to start toxicology studies within the next two years.

Reports of adverse health effects make plain how important such studies are. Several of the Apollo astronauts reported eye irritation, and Harrison Schmitt of Apollo 17 had hay fever-like symptoms on the return journey. It is very unlikely that three days on the moon had any lasting effect on the astronauts' health, but an extended stay could put lunar explorers at risk of contracting silicosis, a potentially fatal lung disease. "No one has studied the effects of moon dust on human physiology," says Larry Taylor. "Now the doctors are finally going to get around to it."

Astronauts will need to know just how much dust they can risk being exposed to, and for how long. "Moon dust is similar in sharpness and abrasiveness to the dust from mining operations," Kerschmann says. He is desperate for a simulant that is as abrasive as moon dust. The grains in JSC-1 are simply not rough enough for his studies because the grinding process that makes the particles smaller also tends to make them smoother.

Perhaps he could borrow some extra-abrasive simulant from Masami Nakagawa, a materials scientist at the Colorado School of Mines in Golden. Nakagawa manages a project affectionately known as Project Dust. You could call him the head dust-buster. Nakagawa is trying to make suitably jagged dust grains by cutting rather than grinding them.

But making the right kind of simulant is only half of the game, he says: researchers will also have to recreate the right environment. The near-perfect vacuum and ultra-dry conditions on the lunar surface probably have a lot to do with the properties of moon dust, such as its powerful static cling. Fortunately, Nakagawa has a unique resource to perform this kind of experiment: a vacuum chamber left over from the Apollo days. The 1-metre-wide cylinder can create a vacuum equivalent to a millionth of a billionth of the density of Earth's atmosphere. "It has been sitting in someone's basement for 10 years," says Nakagawa. After he gets it running again, he plans to spend four years figuring out everything he can about lunar dust - how it moves around, how it attaches to things, how it responds to electric and magnetic fields. Ultimately, Project Dust will tell NASA what kinds of bearings, sealants and lubricants to use, and hopefully how to keep surfaces dust-free.

It may sound more like a small step rather than a giant leap, but that's exactly how NASA is hoping to play things this time. The agency is keen to avoid a rushed programme, like the one in the 1960s that put the first men on the moon. The new analogy is a spiral stairway, in which each turn builds on the ones before.

First NASA has to build a new spacecraft capable of reaching the moon. Then it plans to test it by sending it for short stays to the moon before a much longer manned mission. At the moment Nakagawa is not thinking beyond the second stage. "People are talking about infrastructures for a lunar base, but I don't think we are ready for that discussion yet," he says. "I would like to send astronauts there for two weeks and safely return them. If we can accomplish that, my goals will be met."

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